MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2017/2018

ENT2016 – SOLID STATE ELECTRONICS

(Nano)

17 March 2018
09.00 – 11.00
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.
2. Attempt all **FOUR** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

Question 1

(a) Briefly explain 'Miller indices' in crystallography. [2 marks]

(b) Explain what is meant by a family of planes. Comment if the (0 0 1) and $(\bar{1}\,0\,0)$ planes are of the same family? [3 marks]

(c) Label the planes illustrated in FIGURE Q1(C-i), (C-ii) and (C-iii) using the correct notation for a cubic lattice of unit cell.

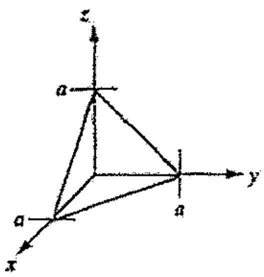

FIGURE Q1(C-i)

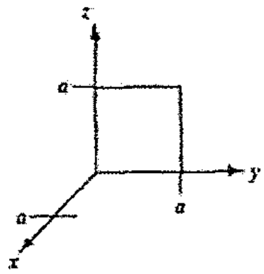

FIGURE Q1(C-ii)

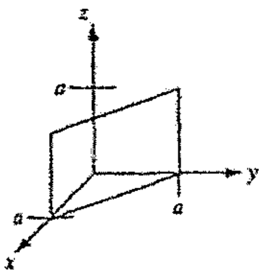

FIGURE Q1(C-iii)

[3 marks]

(d) Consider Niobium (Nb) is deposited on top of a Silicon structure. It is further heated and characterized (above 620 ^{o}C) and observed a body centered cubic (BCC) unit cell structure with a mono-atomic basis having atomic density of the unit cell as 1.6 x10^{22} cm^{-3},

(i) Sketch the (110) plane of the Nb unit cell. [2 marks]
(ii) Calculate the lattice constant. [3 marks]
(iii) What is the atomic density per unit area on the (110) plane? [3 marks]
(iv) What is the nearest neighbor atomic distance for this cell? [2 marks]
(v) What is the volume that each atom can occupy? [1 marks]

(e) Platinum (Pt) has the Face Centered Cubic (FCC) crystal structure. The radius of the Pt atom is 0.1386 nm. The atomic mass of Pt is 195.09 amu (g mol^{-1}). Calculate the density of Pt atoms.

[6 marks]

Continued...

Question 2

(a) With the aid of suitable diagrams, briefly describe the followings:

(i) Schottky and Frenkel defects in crystal structure [2 marks]

(ii) Stacking faults and Twin boundaries [2 marks]

(b) In Sodium chloride, impurity Ca^{2+} and O^{2-} ions would most likely substitute Na^{+} and Cl^{-} ions, respectively. Suggest two possibilities to preserve electroneutrality. If electroneutrality is to be preserved, identify the types of point defects that are possible in NaCl when a Ca^{2+} substitutes for an Na^{+} ion.

[4 marks]

(c) Potential energy (E) for a crystal structure of Na^{+}-Cl depends on the interionic separation r. If for NaCl, M = 1.763, B = 1.192×10^{-104} J m^9 or 7.442×10^{-5} eV $(nm)^9$ and $m = 9$ then at interatomic separation r,

$$E(r) = -\frac{e^2 M}{4\pi\varepsilon_o r} + \frac{B}{r^m}$$

(i) Find the equilibrium separation (r_o) of the ions in the crystal

[4 marks]

(ii) Find the cohesive energy when the *ionization energy* of Na is 3.89 eV and the *electron affinity* of Cl is 3.61 eV.

[6 marks]

(iii) Calculate the atomic cohesive energy of the NaCl crystal in joules/mole.

[3 marks]

(d) Given that the density and atomic weight of Fe are 7.65 g/cm^3 and 55.85 g/mol, respectively, and the activation energy for vacancy formation is 1.08 eV/atom, what is the concentration of vacancies at 850° C?

[4 marks]

Continued...

Question 3

(a) Briefly explain the behavior of light based on the following:

(i) Young's double slit experiment [3 marks]

(ii) Einstein's photo electric effect [3 marks]

(b) Consider an electron in an infinite potential well of width 0.1 nm.

(i) Calculate the ground energy of the electron. [2 marks]

(ii) Find the energy required to move the electron from the ground energy level to the third energy level. [2 marks]

(iii) Can an X-ray photon whose wavelength is 4.12 nm provide the energy in (b)(ii)? Justify your answer. [3 marks]

(iv) Find the uncertainty in the momentum of the electron.

[2 marks]

(c) Electrons are accelerated through a potential difference of 54 V and are directed at a Beryllium crystal with a spacing between atoms of 7.38 x 10^{-9}m. Calculate the de Broglie wavelength and the first order (n=1) angle of diffraction.

[5 marks]

e) In a gas discharge tube, He^{+} ions are to be further ionized to He++ via impact ionization with electrons accelerated by an applied voltage.

[5 marks]

Continued...

Question 4

(a) Illustrate the differences between the energy band diagrams of a metal, an insulator, and a semiconductor.

[3 marks]

(b) Most semiconductor devices operate by the creation of charge carriers in excess of the thermal equilibrium values.

i. Determine the maximum value of the energy gap that a semiconductor, used as a photoconductor, could have if it is to be sensitive to yellow light (600 nm). [3 marks]

ii. A photodetector whose area is 5×10^{-2} cm^2 is irradiated with yellow light whose intensity is 2 mW cm^{-2}. Assuming that each photon generates one electron-hole pair, calculate the number of pairs generated per second.

[4 marks]

iii. From the known energy gap of the semiconductor GaAs (E_g = 1.42 eV), calculate the primary wavelength of photons emitted from this crystal as a result of electron-hole recombination.

[3 marks]

iv. Is the above wavelength fall in the visible range?

[1 mark]

v. Will a silicon photodetector (Si, E_g = 1.10 eV) be sensitive to the radiation from a GaAs laser? Why?

[3 marks]

(c) A Si crystal has been doped with P. The donor concentration is 10^{15} cm^{-3}. Find the conductivity, and resistivity of the crystal.

[3 marks]

(d) A Si crystal is to be doped *p*-type with B acceptors. The hole drift mobility μ_h depends on the total concentration of ionized dopants N_{dopant}, in this case acceptors only, as

$$\mu_h \approx 54.3 + \frac{407}{1+3.745\times10^{-18}\, N_{\text{dopant}}}\ \text{cm}^2\text{V}^{-1}\text{s}^{-1}$$

where N_{dopant} is in cm^{-3}. Find the required concentration of B doping for the resistivity to be 0.1Ω cm.

[5 marks]

Continued...

Useful constants and materials properties:

Physical constants		
Boltzmann's constant	k	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant	h	6.626×10^{-34} J s
Thermal voltage @ 300 K	kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space	m_e	9.10939×10^{-31} kg
Electron charge	e	1.60218×10^{-19} C
Effective density of states in the conduction band (for Si)	N_c	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band (for Si)	N_v	1.04×10^{19} cm^{-3}
Permeability of free space	μ_o	$4\pi \times 10^{-7}$ H/m
Permittivity of free space	ε_o	8.85×10^{-12} F/m
Avogadro's number	N_A	6.023×10^{23} mol^{-1}

Semiconductor Materials Properties at 300 k					
Materials	*Energy gap*	*Intrinsic concentration*	*Electron mobility*	*Hole mobility*	*Dielectric Constant*
Notations	E_g (eV)	n_i (cm^{-3})	μ_e (cm^2 V^{-1} s^{-1})	μ_h (cm^2 V^{-1} s^{-1})	ε_r
Si	1.10	1×10^{10}	1350	450	11.7
GaAs	1.42	2.1×10^{6}	8500	400	13.1
Ge	0.66	2.3×10^{13}	3900	1900	16

End of Paper